Weak Lensing Systematics

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Sources of Systematic Errors

- Separation of stars and galaxies
  — How does one distinguish a star from a galaxy?
  — Where does one demarcate the boundary of a galaxy or the boundary between two overlapping galaxies?

- Measurement of galaxy shapes
  — The measurement of galaxy shapes, corrected for the effects of the Point Spread Function (PSF) of the atmosphere, detectors, and telescope, is linked to a second set of systematic errors.

- Correlations of galaxy shapes, sizes and positions
  — Sources of spurious correlations (physical, algorithmic and instrumental) masquerade as signal
  — Photometric redshift errors can obscure the tomographic signatures of dark energy (**See talk by Jeff Newman**)
  — How should we choose “nuisance” parameters to fit for systematics: thousands or dozens?

Shape measurements on galaxy and star images

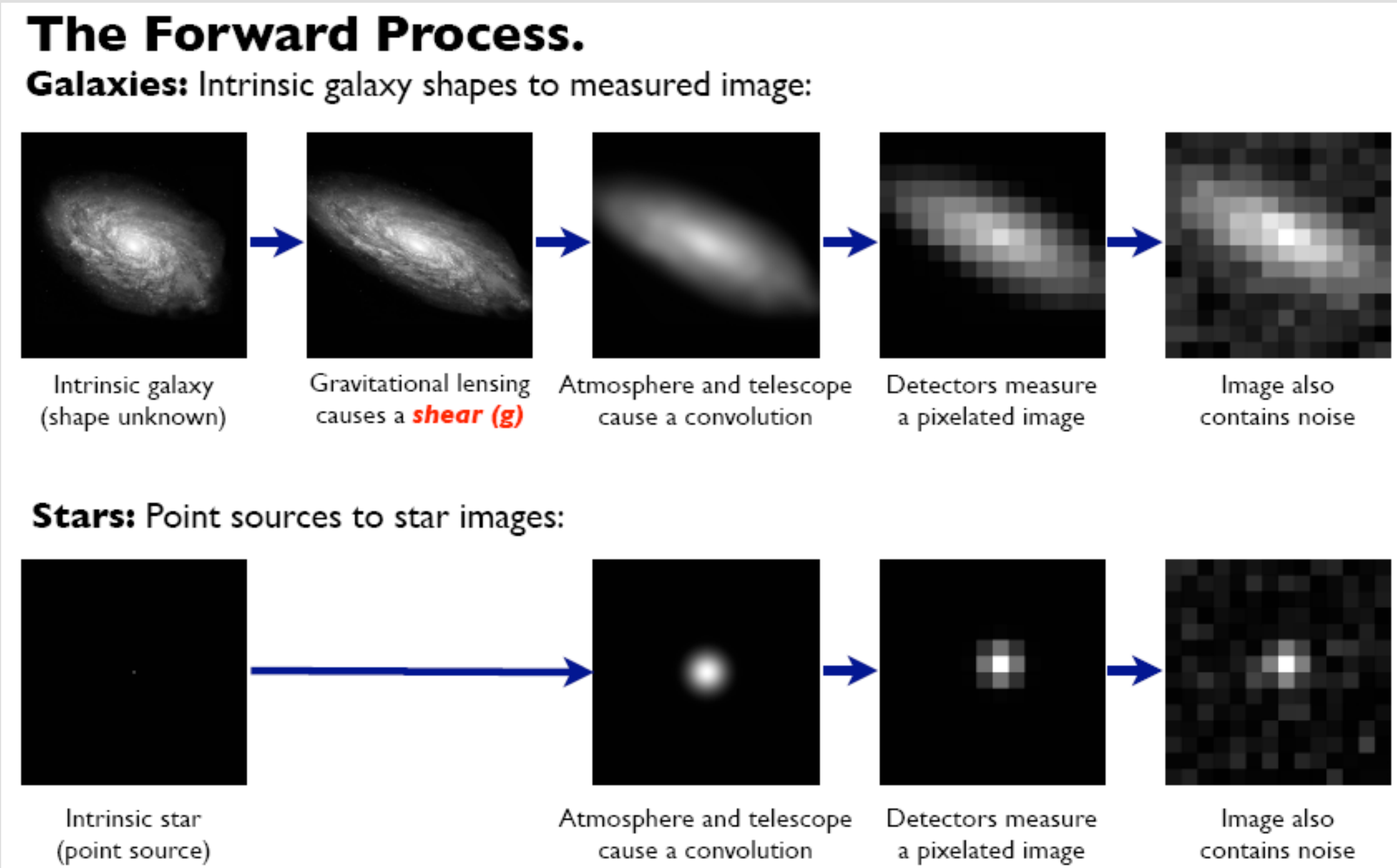


Figure from S. Bridle

Systematic Errors: Overview I

Lensing->cosmology pipeline:

1. Object detection and star-galaxy classification
2. PSF (point spread function) measurement from stars
3. PSF interpolation onto galaxy positions
4. Galaxy shape measurement and PSF deconvolution (or equivalent)
5. Measurements of shear correlations and covariances
6. Tomography (redshift binning) and inference of cosmological parameters

Systematic errors that can enter into the various steps of the lensing->cosmology pipeline:

- Theory uncertainty/high ℓ information
- Intrinsic alignments
- Photo-z calibration
- Shear calibration
- PSF correction

Systematic Errors: Overview II

- For cosmological applications, essentially all lensing systematics may be classified as one of three kinds:

  1. Additive, 2. Multiplicative, 3. Redshift errors

$$\hat{\gamma}(z_s) = \gamma(z_s + \underset{3}{\delta z})\left[1 + \underset{2}{\zeta}(z_s)\right] + \underset{1}{\gamma_{sys}}(z_s)$$

- Intrinsic alignment errors (1)
- Spectroscopic calibration of photo-z's (3)
- Shear calibration (2)
- PSF correction (1) (also connected to shear calibration)

Requirement on Systematics

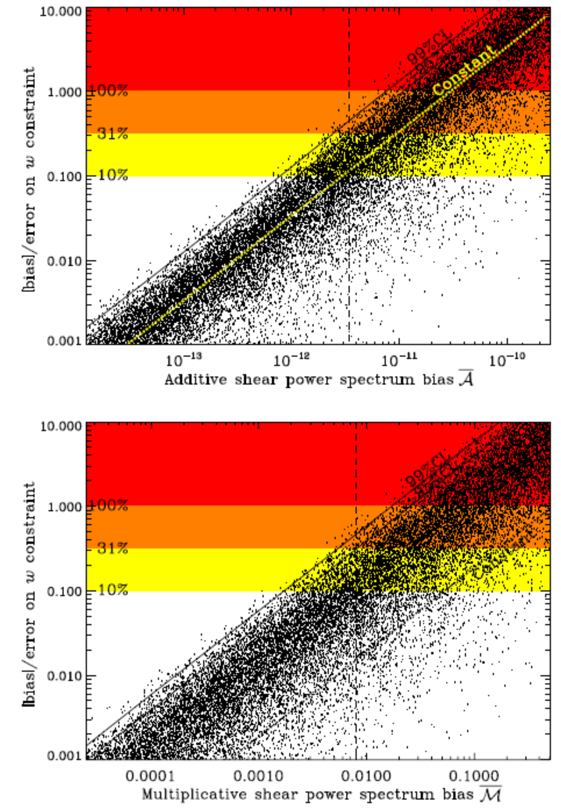


Figure 3. The bias on measurements of the dark energy equation of state parameter w from weak lensing surveys with **(top panel)** additive and **(bottom panel)** multiplicative shear measurement systematics. Each data point shows a random realisation of systematics with a unique dependence upon angular scale and redshift (for clarity, only one in three are plotted). The dotted diagonal lines show the bias on cosmological parameters if the shear measurement systematics are constant. The solid diagonal curves show limiting values that include 95% and 99% of random realisations with a given value of $\overline{\mathcal{A}}$ or $\overline{\mathcal{M}}$. An all-sky 3D cosmic shear survey will only be deemed successful if the measurement bias is $\lesssim 31\%$ of the statistical measurement error. At 95%CL, this will require (vertical dashed line) shear measurement better than $\overline{\mathcal{A}} \lesssim 3.5 \times 10^{-12}$ if $\mathcal{M} \equiv 0$, and $\overline{\mathcal{M}} \lesssim 8.0 \times 10^{-3}$ if $\mathcal{A} \equiv 0$.

- From Massey et al 2013
- Additive and multiplicative shear errors can both bias dark energy constraints
- Systematics must be kept well below statistical errors

Planned Work on Lensing Systematics: 1

- Stage III surveys: DES, HSC/Subaru and other surveys in the next 5 years
  - Extensive tests with galaxies out to z~1 Theoretical predictions of power spectra at 1-2 percent level expected
  - Shear calibration, PSF correction will be tested to order of magnitude better than present tests from data
  - Photo-z calibration out to z~1.5 will be attempted to better than 0.01 level

- Targeted observations to learn about the atmosphere

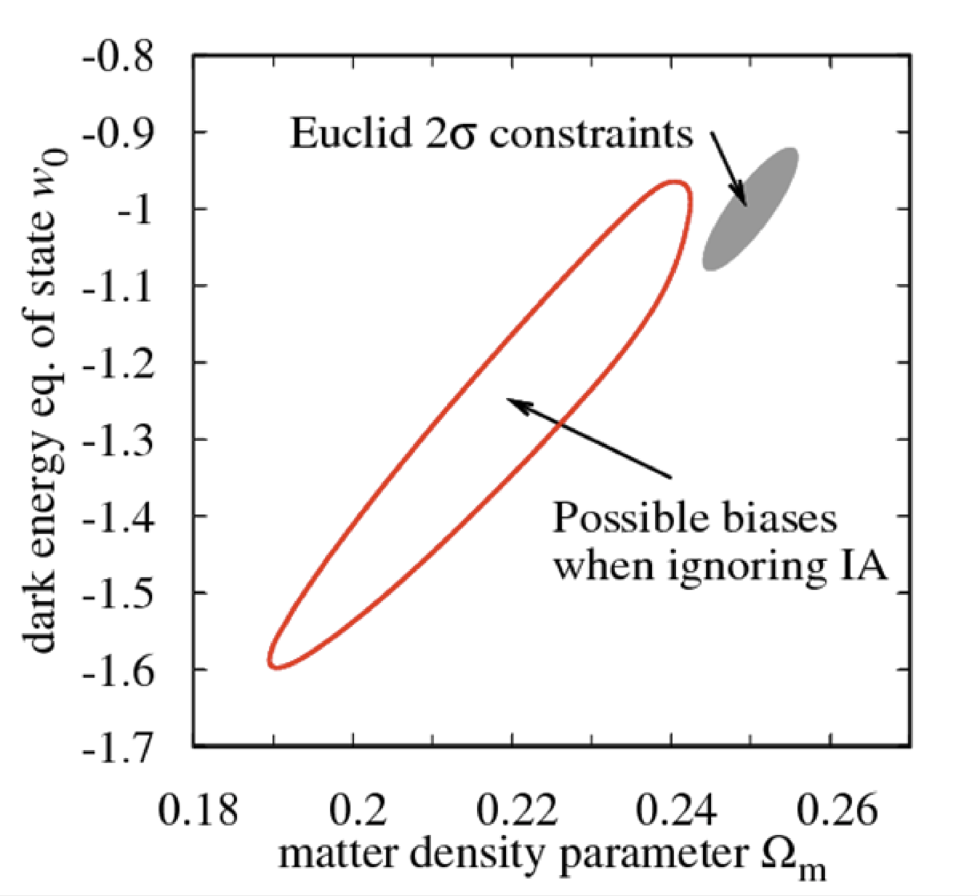
- Detector characterization
  - CCDs suffer from charge transfer efficiency degradation and non-uniform pixel sizes
  - NIR detectors suffer from persistence and interpixel capacitance
  - All detectors have signal non-linearities

- Algorithm development and tests on simulated images
  - Multiple approaches to shape measurement will be tested with increasingly realistic images
  - GREAT3 using Galsim underway

Planned Work on Lensing Systematics: 2

- Quantify color dependence of PSF and mitigation techniques
  - HST data can be used (Semboloni et al 2013)
- Simulations of the LSST, Euclid, WFIRST telescopes with realistic galaxy images
  - Expect detailed understanding of PSF patterns
  - Understanding of trade-offs between number of exposures, PSF stability, PSF size, depth
- Numerical simulations
  - Non-linear modeling, gas physics?
  - Intrinsic alignments, models of galaxy and halo formation
- Photo-z method development and spectroscopic calibration using DESI, PFS
  - Jeff Newman talk

Intrinsic Alignments



- Example Euclid constraints (gray) and possible biases if IA are ignored (Joachimi et al 2011)

- Modeling and understanding sources of IA is key

GREAT3

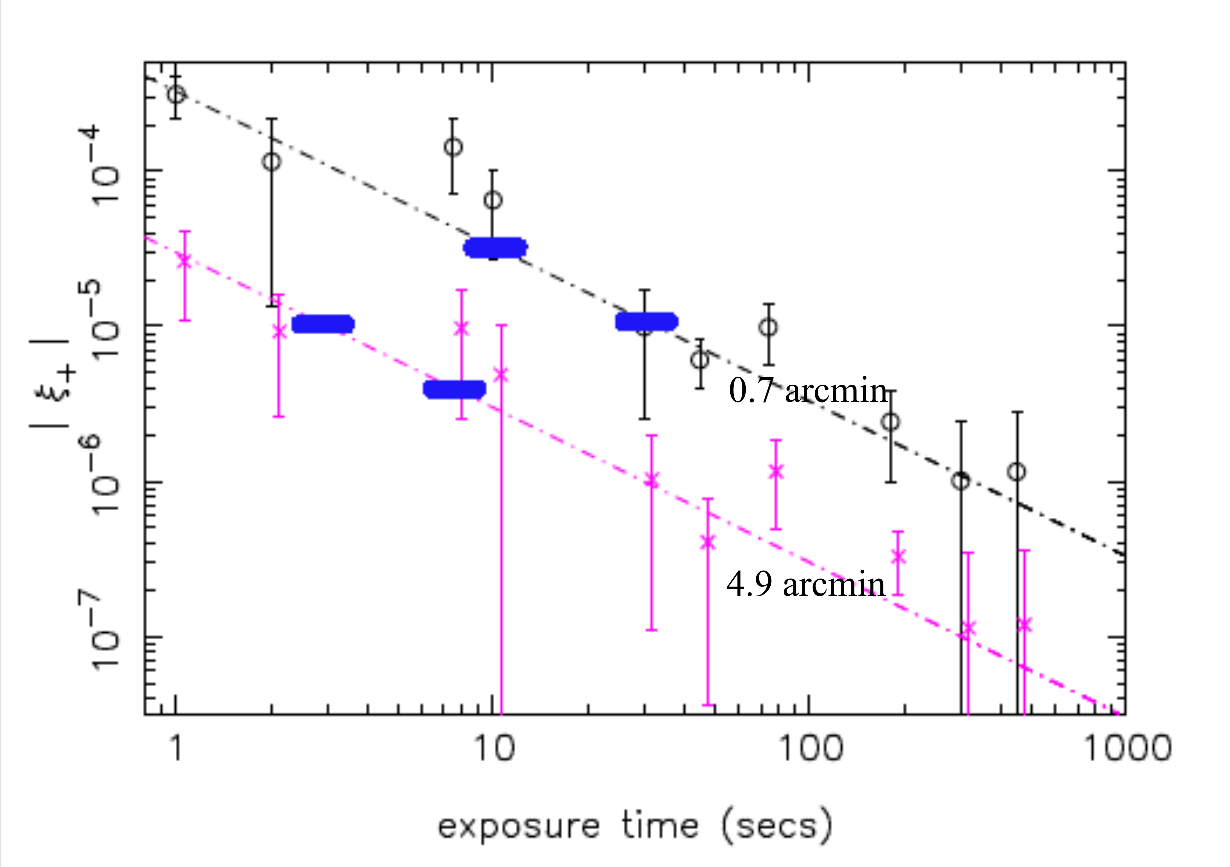
- Ongoing community challenges
- Realistic galaxies and PSFs now being included
- Extrapolating from GREAT08 and GREAT10, GREAT3 will allow us to reach required accuracy of LSST, Euclid, WFIRST
- Are the simulations realistic enough?

Challenge kickoff workshop at JPL, Aug 20-22

Described in "Challenge Handbook" (Mandelbaum, Rowe et al. in prep), which will be on arXiv by Aug 20

5 experiments	x 2 shear types	x 2 observation types	= 20 branches
Control Realistic galaxies Variable PSFs Multi-epoch Everything	Constant Variable	Space Ground	Control/constant/space Control/constant/ground Control/variable/space Control/variable/ground ...

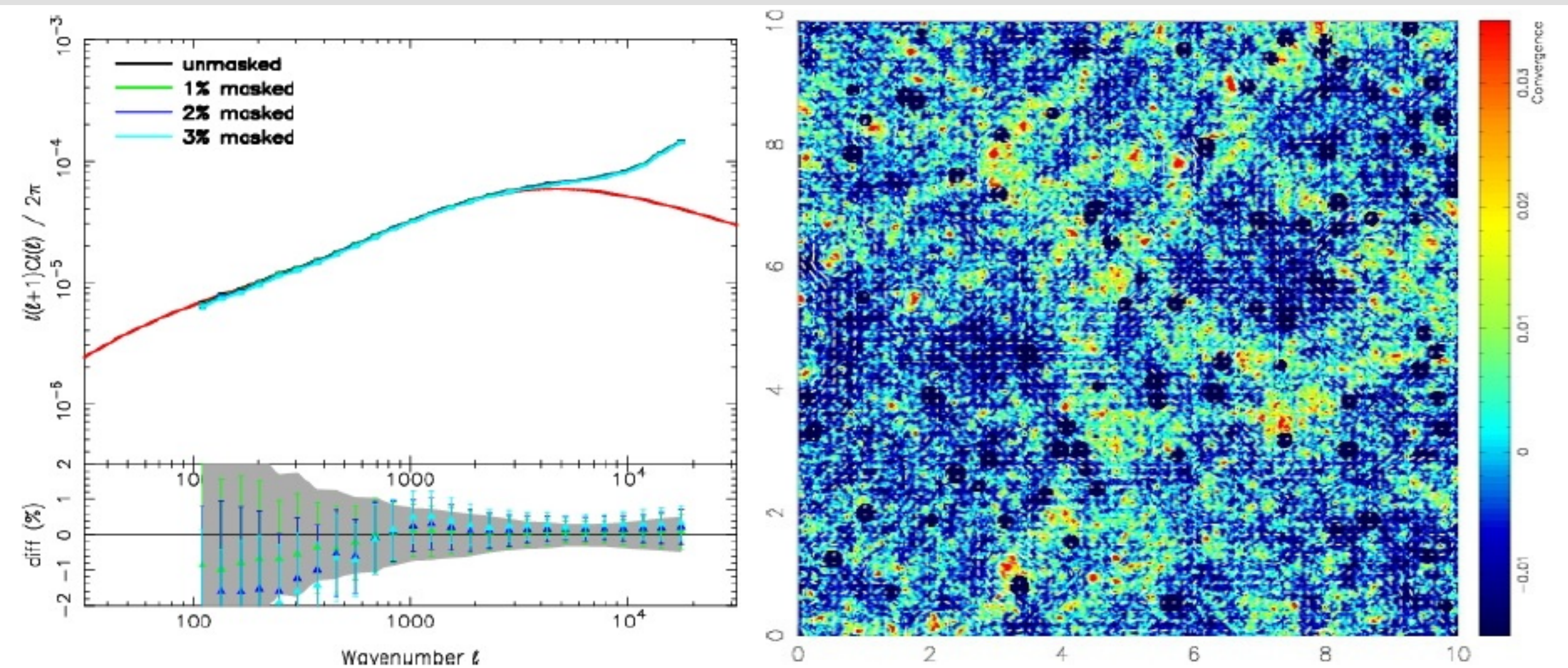
Understanding the Atmosphere



- Ellipticity correlations due to the atmosphere reduce approximately as $1/t_{exposure}$
- Validated with Subaru and CFHT data that spans 1-800 seconds (*Wittman 2005*; *Heymans et al 2011)*
- With over 100 LSST visits of 30 seconds each in *r*/*i* filters, atmospheric contribution to ellipticity correlations will be small on scales >1 arcmin: i.e. "routine" PSF correction sufficient.

Simulation Errors and Uncertainties

- Errors in power spectrum estimation must be accounted for in error budgets (must compare observations to theory)
- Need many computational expensive simulations
- Eventually need to include more physics in the simulations



From Laureijs et al 2011

Current Status

- WL has the potential to be the most powerful DE probe
  - —Must control observational, theoretical, and astrophysical systematics
  - —Ongoing work in all areas is making progress, sometimes within a project, sometimes community wide
- Space (COSMOS, 1.7 square degrees) and ground-based (CFHTLS, 150 square degrees) surveys are limited by systematics
- New surveys and instruments are using lessons learned
- DES and PFS will be the proving ground for LSST, Euclid, and WFIRST-AFTA

Multiple Strategies for a difficult task

- **LSST**
  - **Many exposures over a long time baseline**
  - **Marginalize over atmosphere**
  - **Multiple filters**
  - **Reaches great depth**

- **Euclid**
  - **Calibrate wavelength dependent PSF/color gradients using HST data**
  - **Deep fields with multiple exposures for calibration**
  - **Very wide survey with small, stable PSF to self calibrate**
  - **Optimize detector readout strategy**

- **WFIRST**
  - **Multiple redundancies in shape measurements**
  - **Multiple filters**
  - **Critical sampling with dithering, optimal image combination (IMCOM; Rowe et al 2012)**
  - **Full characterization of detectors**